Project Title:	**Materials and Intrinsic Properties in the J_c Dependence on Thickness of *Ex-Situ* YBCO Coated Conductors**
Organization(s):	**Los Alamos National Laboratory, Oak Ridge National Laboratory, and the University of Wisconsin**
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Project Purpose and FY 2003 Objectives: This is the initial evaluation of this collaborative research effort. This project started with several common goals and related CRADA commitments that formed our purpose and objectives. One goal was to understand the decrease in critical current density (J_c) as a function of $YBa_2Cu_3O_7$ (YBCO) film thickness, separating the materials properties from the intrinsic dependences. The second goal was to correlate microstructures resulting from the ex-situ conversion processes (evaporated precursors and MOD) with film performance (Structure-Property-Chemistry). A third goal was to understand the formation process of the YBCO films from the precursors and develop methodologies for controlling the phase development and structure (Structure-Processing-Chemistry). A fourth goal was to produce high current YBCO coated conductors.

FY 2003 Performance and FY 2004 Plans: Significant progress was made in all four of the FY 2003 objectives. (1) The dependence of J_c on layer thickness d was determined for YBCO epitaxial films on RABiTS, IBAD-YSZ, and YSZ single crystals. YBCO films (up to 3 μm) were grown by the ex situ BaF_2 process using evaporated precursors. Complementary data of through-thickness $J_c(d)$ were collected by stepwise thinning of thick film specimens by ion milling. Intrinsic and materials related issues pertaining to $J_c(d)$ were identified. (2) Transmission electron microscopy (TEM) was used to characterize fully processed YBCO coatings on all substrate types. Samples were selected to highlight structural differences between films exhibiting different J_c and to coincide with specimens used in the through-thickness J_c studies. Results were contrasted with AMSC MOD and LANL PLD YBCO films. (3) TEM studies of quenched and partially converted YBCO films revealed the formation process and competing secondary phase development. A database is being built from which improved processing schemes are expected to emerge. (4) Ex-situ conversion of relatively thick YBCO precursors lead to high critical current (I_c) YBCO coated conductors. Best values exceeded 200 A/cm (77 K) for YBCO films on RABiTS and IBAD-YSZ substrates. High-J_c results were also obtained from IBAD-MgO based coated conductors.

Research plans for FY2004 are to continue ion milling and electron microscopy experiments on thick ex-situ YBCO films in order to further clarify materials and intrinsic effects on the thickness dependence of J_c. Specific plans include:

1. Determine whether the established baseline $J_c(d)$ dependence is primarily a materials effect (due to imperfect growth) or the result of a thickness-independent microstructure for flux pinning (intrinsic effect).
2. Fabricate and characterize YBCO epitaxial films at different rates and conditions of the ex situ process to document changes in film properties as the structure and chemistry are systematically changed.
3. Determine the effect of the CeO_2 buffer layer on the growth and properties of thick films.
4. Increase I_c for YBCO films on RABiTS and IBAD substrates to values >400 A/cm (77 K) by either increasing the YBCO thickness and/or decreasing the falloff in J_c as a function of d.

FY 2003 Results: Key results from the FY 2003 program are summarized below.

1. The ex situ conversion process produces a consistent and reproducible dependence of J_c on the YBCO layer thickness. Films were grown on three varieties of RABiTS, IBAD-YSZ, and single-crystal YSZ with CeO_2 as the interface layer with YBCO. A large dataset was compiled for YBCO coatings on reel-to-reel RABiTS, featuring a Ni-W alloy as the base metal. A key finding is the observation of a near-complete absence of substrate related effects on $J_c(d)$, after texture related differences are taken into

account. Analysis shows that $J_c = J_\Phi \cdot j(d)$ may be expressed as the product of a texture dependent scaling factor J_Φ and an invariant function $j(d) = 1/d^{1/n}$ describing the dependence on layer thickness. Good agreement with the combined dataset is obtained for $n \cong 2$, indicating an inverse-square-root dependence. This functional dependence agrees with theoretical predictions from a collective pinning model. On the other hand, TEM indicates that films exhibit spatially non-uniform microstructures, varying with *d*. This gives rise to questions related to the role of intrinsic effects versus materials properties and the nature of defects that control J_c.

2. Through-thickness measurements of $J_c(d)$, were performed to ascertain the possible existence of so-called "dead" layers in thick YBCO coatings. The data provide conclusive evidence for the absence of dead layers in YBCO films made by the ex-situ conversion process. Information on the relation between through-thickness microstructure and J_c also was obtained. Thinning data were compared to 1 μm thick, high-I_c AMSC MOD coatings.

3. TEM has been used to study the microstructure of fully and partially processed YBCO films. It is found that the films exhibit a substrate-independent, dense microstructure through thickness (consistent with the absence of dead layers) marked by what appear inhomogeneous growth events. Large-grained YBCO features are typically found near the substrate interface, reminiscent of the effects of liquid-assisted growth or solidification from a liquid. By contrast, small-grained and highly defective YBCO is found near the surface of the film. Quench studies were initiated to characterize and understand this phase development.

4. A consequence of the inverse-square-root dependence of J_c is that I_c increases monotonically, proportional to $d^{1/2}$, with a texture-dependent proportionality constant. The best result to date for thick (2.9 μm) YBCO on IBAD-YSZ is 270 A/cm (77 K). For YBCO on the reel-to-reel RABiTS, the best result (188 A/cm) is for a 2.4-μm-thick coating, although one 1.37-μm-thick film exhibited an I_c = 219 A/cm. This latter result, which could not be reproduced thus far, stems from a high J_c value practically at the level observed for thin YBCO. TEM analysis of the microstructure is in progress. A J_c value of 2 MA/cm^2 (77 K) was obtained for 0.35-μm-thick YBCO on IBAD-MgO.

Research Integration: This research group represents a tight inter-lab, university, and national industry collaboration in YBCO coated conductor research, where each partner brings a unique expertise to the collaboration. Ex-situ conversion is a promising deposition process for large-scale commercial deployment as illustrated by our industry partner, American Superconductor Corporation. Additional external collaborators include: NIST-Gaithersburg (phase development) and NIST-Boulder (strain effects), ANL (Raman spectroscopy), Stanford University and other participants in the MURI project (information exchange), Kyushu University, Japan (J_c(H,T)), and Institute de Ciencia de Materials de Barcelona, Spain (granularity effects).